STATIONARY NEUTRON RADIOGRAPHY SYSTEM

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INTRODUCTION

General Atomics (GA) is currently under turn-key contract to construct a Stationary Neutron Radiography System (SNRS) at McClellan Air Force Base, Sacramento, California. The SNRS is a custom designed neutron radiography inspection system, see Fig. 1, which utilizes a 1000 kW TRIGA reactor as a neutron source to inspect aircraft components for corrosion and other defects. The SNRS project is made up of four major systems: the Shielding and Containment System (SCS); TRIGA Reactor System (TRS); Neutron Beam System (NBS); and Component Inspection System (CIS). The SNRS project is currently close to completion with the construction phase completed and the equipment installation and testing phase well underway.

Neutron radiography is a mature non-destructive inspection technique and has been used successfully for many years in the detection of hydrogen-containing materials inside of or behind metal structures. Accordingly, the application of neutron radiography to interrogate aircraft control surfaces for the presence of moisture or corrosion in aluminum honeycomb structures is straightforward and has been demonstrated on a piece-parts, low-throughput basis. The use of neutron radiography for

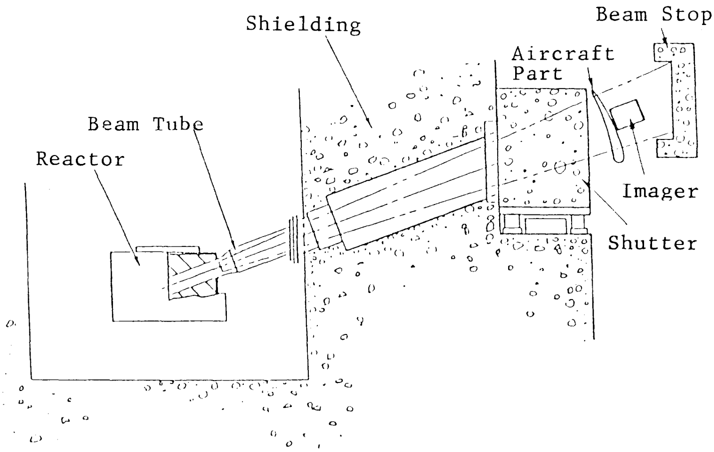

Fig. 1. SNRS System Configuration.

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9
Edited by D.O. Thompson and D.E. Chimenti
Plenum Press, New York, 1990

integrity verification of military pyrotechnics has also been well demonstrated with a variety of neutron sources including Van De Graaff accelerators, Californium-252, and small nuclear reactors. The use of real-time imaging with X-radiography and neutron radiography does not have as long a history of demonstrated performance, but has emerged within the past several years as a viable alternative to film recording of radiography. It introduces the possibility for rapid scanning of components and concentration on specific areas of interest. The emergence of robotics technology, with the possibility of programmed and precisely reproducible scanning modes, combined with neutron radiography and real-time imaging, provides a solid technical basis for establishing the SNRS.

The most robust neutron source for neutron radiography is a nuclear reactor and the throughput demands of the Stationary Neutron Radiography System at McClellan AFB required this type of neutron source. However, installation of a reactor results in a stationary source, whereby parts to be interrogated must be passed through the neutron beam by means of fairly sophisticated parts handling systems. This necessarily restricts the application of NR to parts that can be readily removed from the aircraft to be inspected. For the NDE of intact aircraft by neutron radiography, particularly in sections of the hull where corrosion is a problem, a portable neutron source such as a neutron generator on a boom may be performed. This technique can be used with both film and electronic imaging systems. In these applications, both expedient shielding and distance separation can be used to maintain reasonable radiation levels for operating personnel.

The primary mission of McClellan Air Force Base is the maintenance of aircraft. This requires adequate methods of inspection. A major maintenance problem is the early detection of aluminum corrosion or the presence of moisture within the aircraft panels constructed with honeycomb. If not detected and repaired, this corrosion can rapidly propagate, causing structural failure, fuel leaks, fires and loss of aircraft. At the present time, there is no inspection method capable of detecting low-level corrosion or moisture in the honeycomb structure. The SNRS will provide this, and other important capabilities.

The thin-walled aluminum core of bonded honeycomb panels is particularly susceptible to corrosion. Currently eighty percent of the aircraft panels require some rework at each four-year maintenance cycle. The problem of corrosion is expected to increase with the aircraft's age. The F-111's are now about 15 years old, and scheduled to remain in service for an additional 15 years or more. When in service, many of the panels of the F-111 are loaded with fuel held under pressure. Even early corrosion can cause leaks, fire, and loss of aircraft. Neutrons, unlike x-rays, can provide very high sensitivity to detect corrosion due to the presence of hydrogen in the corrosion product.

In addition to reducing the risk of returning faulty parts to service, neutron radiography will:

a) Increase the precision with which corrosion is located, thus permitting local rework and heating to evaporate moisture thus reducing the risk of blown honeycomb core during the autoclave processing.

b) Allow tracking of corrosion history.

c) Provide inspection capability for pyro-technics, stress corrosion cracks, hydraulics and electrical insulation.

Shielding and Containment System

The SCS is a three-level rectangular shaped 1583 M^2 (17,041 ft^2) enclosure that incorporates the TRIGA reactor, four neutron radiography bays (shielded rooms), staging areas, equipment areas and control rooms, see Fig. 2. The SNRS is sized to accept an intact F-111 wing as the largest item to be inspected. There are more than 54 different aircraft components which must be accommodated within the SNRS.

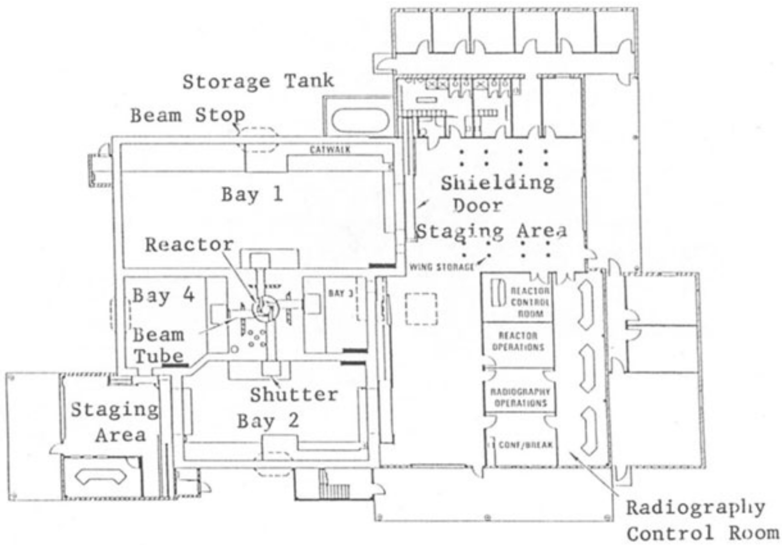

Fig. 2. SCS Floor Plan.

TRIGA Reactor System

The reactor system is a standard design 1000 kW, natural-convection--cooled TRIGA reactor with the graphite reflector modified to accept the source ends of the four neutron radiography beam tubes which terminate in separate neutron radiography bays. The reactor is located near the bottom of a water-filled aluminum tank 7 ft. in diameter and about 26 ft. deep. The tank is surrounded by concrete shielding on the sides and bottom. Access to the core is through the water from the open top of the tank. The reactor is monitored and controlled by a state-of-the-art computer-based instrumentation and control system featuring color graphics display, self-calibration, and automatic logging of vital information. Both manual and automatic control options are available to the operator.

The inherent safety of this TRIGA reactor has been demonstrated by the extensive experience acquired from similar TRIGA systems throughout the world. This safety arises from the large prompt negative temperature coefficient that is characteristic of uranium-zirconium hydride fuel-moderator elements used in TRIGA systems. As the fuel temperature increases, this results in a mechanism whereby reactor power excursions are terminated quickly and safely.

Neutron Beam System

The NBS consist of a beam tube, aperture, shutter and beam stop for each of the four radiography bays. The NBS features an optimized "source end" design of the graphite reflector and beam-extraction "hole" to ensure maximum thermal flux and minimum non-uniformity at the image plane. The beams have an L/D ~ 100:1 with a thermal neutron flux of approximately 6.4×10^6 n/cm^2.s at an operating power of 250 kW. All four beams are capable of simultaneous operation.

Two shutters are installed at the output end of each beam tube. A massive "biological" shutter has an "open" position and a "closed" position to allow safe personnel access to the exposure bay. A fast-operating, lightweight shutter, attached to the biological shutter, allows the thermal neutron beam to be attenuated for accurately controlling film exposures. Beam stops are provided in each bay to minimize the thermal neutron albedo.

Component Inspection System

The CIS consist of three subsystems; the Component Positioning System (CPS), the Neutron Imaging System (NIS), and the Image Interpretation System (IIS). Fig. 3 provides the SNRS design workload.

Component Positioning System

A CPS is used to position aircraft components in each of the four inspection bays. The CPS in bays 1 and 2 are totally automated and provide five independent axes of motion.

Each of these bays is optimized to provide positioning of components by size. Bay 1 is designed to handle the largest components, F-111 wings, see Fig. 4 & 5. The five axis bay 1 robot will accommodate all of the smaller components with proper fixturing.

Bay 2 is optimized to handle other large components. The F-111 horizontal stabilizer is the largest. This bay can also accommodate all of the smaller components with proper fixturing.

Bay 3 is unequipped due to the current funding shortage, however, it has been sized to handle small components up to 5 ft by 5 ft.

Bay 4 is sized to accommodate several of NASA's solid rocket booster (SRB) components. However the bay will be initially equipped with fixturing to hold pyrotechnics and film cassettes that are moved in and out of the inspection area manually.

Neutron Imaging System

The NIS consists of components which transform the neutron distribution into a video image. It also contains the sensors to measure the incoming neutron flux and a system to mark defects observed by the operator. The heart of the NIS is a 9-in.-diameter neutron-sensitive image amplifier. This device uses an internal Gd_2O_2S converter screen, and deposits photocathodes to image and brighten the original neutron distribution to form an image on an output phosphor. This amplified image is coupled to a high-performance camera through a pair of ultra-fast collimator lenses. This arrangement provides a very sensitive and wide dynamic range analog imaging system capable of producing

BAY 1	All parts	200 wings/year
BAY 2	All parts, except wings	500 sq ft/day
BAY 3	Small and curved parts	200 sq ft/day
BAY 4	Pyrotechnics	As needed

Fig. 3 SNRS Workload.

AXIS	POSITION	LIMITS OF MOTION	SPEED FOR HEAVIEST COMPONENT	FULL TRAVEL TIME
PITCH	PERPENDICULAR TO	−5 DEG + 40 DEG	10 DEG/20 S	80 S
Z	CENTERLINE OF CART WHEN CART IS CLOSEST TO BEAM	0 TO 9 FT	1 IN./S	−108 S
YAW	COMPONENT PERPENDICULAR TO BEAM	±15 DEG	15 DEG/108 S	−108 S
Y	COMPONENT AT LOWEST POSITION IN BAY	0 TO +13 FT	6 IN./10 S	~260 S
X	TOTAL COMPONENT TRAVEL	33 FT	0–2 IN./S (SCAN)	198 S AT 2 IN./S
			6 IN./S (NON-SCAN)	66 S

Fig. 4 CPS-1 Design Criteria.

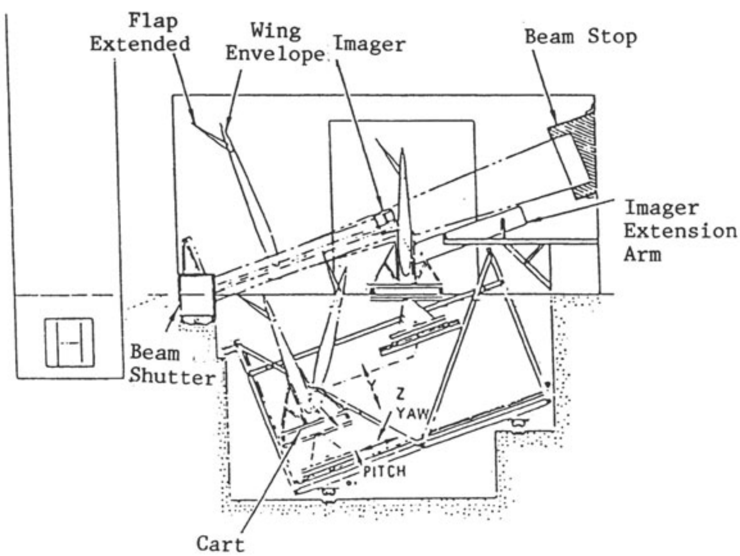

Fig. 5 CPS-1.

excellent real-time radiography over two orders of magnitude of flux from 10^5 n/cm^2-s to greater than 10^7 n/cm^2-s.

Built into the neutron imager are two subsystems that make its use more quantitative. These are the neutron current gauge and a defect marking system. The neutron flux gauge consists of two small U-235 fission chambers; one located at the beam exit port and the other located beside the image amplifier. This pair of gages are read out in the counter mode by a dual scaler-timer so that their rate can be directly interpreted in current units. The two flux measurements can be used to monitor correct system operation, determine average neutron attenuation through a part, and provide a means of calibrating the neutron absorption measured by the imager.

The defect maker system is a spray-jet ink marker mounted next to the image amplifier entrance window. The operator will paint one or more spots to mark the damage and for repair at a later date.

The entire NIS package provides a complete set of input data to the image interpretation system which then aids the operator in interpreting the image appearing on the monitor.

Image Interpretation System

The purpose of the IIS is to collect, process, and display data from the NIS in a manner which best aids the operator to interpret real-time images for detecting the presence of corrosion or other flaws. Each system operation has been optimized with this goal in mind. The choice of hardware has been, in particular, specifically selected to provide the unique characteristics required for effective real-time detection and interpretation of corrosion products on aircraft components. In addition, the IIS is capable of storing image sequences during the inspection and retrieving them later for comparison or review.

The IIS functions by digitally storing and processing images to improve their contrast and effective resolution. The IIS performs all of the standard image processing functions of noise reduction, contrast stretch, and edge enhancement through its flexible pipeline processor and multiple frame buffers. In addition, the IIS uses a unique field-flattening procedure to permit the sensing of very faint quantities of corrosion in real-time images. This is accomplished by special organization of the components which permits the simultaneous correction for the imager response and neutron distribution to the image, as well as image integration and processing. This is a critical feature because the indications of corrosion within the image are often smaller than the non-uniformities in the system. The system is further enhanced by an interactive contrast stretch and pseudo-color display which permit the windowing of typical neutron images into color groups that represent particular areas of the part. On a typical image, the aluminum skins and honeycomb may appear blue, the corrosion pink and the sealant nearly white. This fine separation of image contrast in a smooth and controllable way not only eases the operator's task of interpretation but further provides a quantitative means of determining the level of the corrosion problem.

Data is stored on a 1/2-in. industrial VHS video recorder. Additional capabilities are provided for storage onto a 1-gigabyte optical disk as a system upgrade. Hardcopy video images are also available within seconds to provide a convenient means of referencing images for rework orders. Video cursors, as well as keyboard alphanumeric titles,

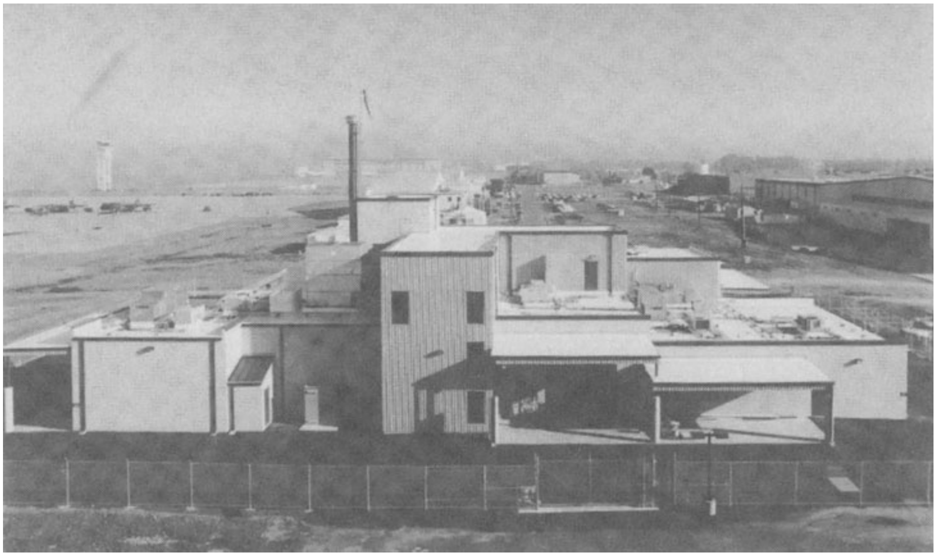

Fig. 6 SNRS.

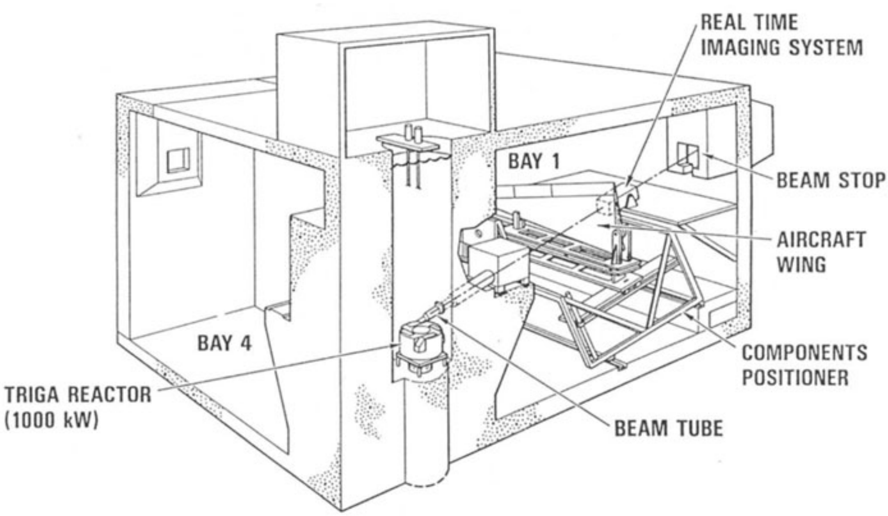

Fig. 7 SNRS System Isometric.

can be overlayed on the image to augment the audio commentary on the video tape record.

The images from the system are displayed on three monitors on the operator console. The video processor can display two different images simultaneously. The third monitor is used to retrieve stored analog images from video tape to be compared with the processed data. A video switcher permits the switching of live and processed images between the monitors. All components and software used in the IIS are modular and can easily be expanded and upgraded as needed. In particular, the IIS is very well suited for advanced frequency domain processing and automated pattern recognition tasks. The IIS represents the most advanced image processing equipment commercially available and will provide a long service life of high-performance operation on the SNRS project.

CONCLUSION

The SNRS construction activities have been completed, Fig. 6. We will be filling the reactor tank with water during September 1989, in preparation for reactor startup. Robotic system installation has started in Bay 1 and the Bay 2 system is being operated in San Diego. The SNRS is scheduled to be completed by January 15, 1990. Fig. 7 shows an isometric view of the TRIGA reactor system, neutron beam system, component positioning system, and shielding and containment system.